EVALUATION OF WHEAT GENOTYPES FOR HEAT TOLERANCE

A Thesis
By

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Examination Roll: MS-160806

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ABSTRACT

Two experiments were conducted at the Dr. Purnendu Gain Field Laboratory and Plant Breeding Laboratory of Agrotechnology Discipline, Khulna University, Khulna during the period from 04 December, 2016 to 23 March, 2017 to identify wheat genotypes for heat tolerance. Eleven wheat genotypes *viz.*, BARI gom-20 (Gourab), BARI gom-21(Shatabdi), BARI gom-22 (Sufi), BARI gom-23 (Bijoy), BARI gom-24 (Prodip), BARI gom-25, BARI gom-26, BARI gom-27, BARI gom-29, BARI gom-30 and Sourov were used as the study materials. The genotypes were evaluated in randomized complete block design (RCBD) and complete randomized design (CRD) with three replications. A simple analysis of variance was performed on plant height, number of leaves/plant, tillers number/plant, number of grains/spike, total grain weight, 1000 grain weight, straw weight and harvest index. To evaluate the sensitivity or tolerance level of the genotypes to heat stress, five indices namely stress susceptibility index (SSI), stress tolerance index (STI), geometric mean to product (GMP), tolerance index (TOL) and membrane stability index (MSI) were studied. The response of BARI gom-20 (Gourab), BARI gom-21 (Shatabdi), BARI gom-24 (Prodip) and BARI gom-26 were better in terms of stress tolerance index (STI), geometric mean to product (GMP), tolerance index (TOL), membrane stability index (MSI) and grain yield both under stress and non-stress condition. Therefore BARI gom-30 showed the lowest stress tolerance index (STI), geometric mean to product (GMP), tolerance index (TOL), membrane stability index (MSI) and grain yield. So, BARI gom-24 (Prodip), BARI gom-21(Shatabdi), BARI gom-20 (Gourab) and BARI gom-26 were considered as heat tolerant. Among the eleven genotypes BARI gom-30 showed the lowest performance and was considered as a heat susceptible genotype.

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CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops and widely grown crop in the world. Wheat is a source of protein and it ranks second after rice as a source of calories in the diets of consumers in developing countries. For reducing pressure on rice, wheat is chosen as an alternative winter food crop. The total production was 5.32 million tons, as against an estimated consumption of 10.48 million tons (CONAB, 2014). Wheat grown areas are often located in regions of lower latitude where the heat stress is the main factor limiting grain production (Lillemo *et al.*, 2005). Wheat production is affected by heat stress at any growing stage. At the grain filling stage of wheat (10 days after anthesis to physiological maturity) high temperature stress causes yield loss because it adversely affects physiological traits, individual grain weight (IGW) and finally yield. The first visual symptom of high temperature stress is lower chlorophyll content in wheat, which acts to damage thylakoid membrane, lipid peroxidation of chloroplast membranes, and damages chlorophyll biosynthesis. Chlorophyll loss, in turn, is an important factor to a loss in the photosynthetic capacity of wheat leaves. Reynolds *et al.* (1994) reported a significant correlation between the rate of chlorophyll loss and photosynthetic capacity of flag-leaves at the grain filling period of wheat grown in a hot environment. According to the estimates a rise in temperature of 1°C in the wheat growing season could reduce the wheat yields by about 3-10%.

As a staple food wheat gains more importance on changing climate scenario, which is due to rising temperature. Stress due to high-temperature has emerged as a major constraint for the successful wheat production worldwide (Hays *et al.*, 2007; Kumar *et al.*, 2012a, b)

In Bangladesh, temperatures would rise 1.3°C by 2030 and 2.6°C by 2070, compared with mid-20th-century levels (Manabe *et al.*, 1991). The annual mean temperature of Bangladesh is 25.75°C and is expected to rise 0.21 °C by 2050 (Karmakar and Shrestha, 2000). Karttenberg *et al.* (1995) stated that crops may be exposed to more thermal stress in the near future since global warming is expected to increase temperatures by 2°C by the middle of the 21st century. In Bangladesh, mean temperature in winter (rabi) has risen by 0.66°C since 1990 and a further rising of 2.13°C by 2050 is predicted (Poulton and Rawson, 2011). A rise in temperature can be expected to increase the severity of *Bipolaris* leaf blight and other wheat diseases in the future because a warm and humid climate favours the development and spread of the pathogen. Changes in the virulence pattern of this pathogen rendering increased susceptibility of wheat varieties are also not unlikely. Increasing temperature might also favors the development and adaptation of wheat stem rust, which can tolerate higher temperatures than other rusts. Yield losses due to leaf rust are usually <10%, but can be 30% or more depending on the level of susceptibility, environmental conditions and the stage of crop development at the initial stage of infection (Singh *et al.*, 2002).

In southern part of Bangladesh farmers are seldom encouraged to wheat cultivation because of low yield of wheat due to short winter, high temperature, late sowing date and salinity. As a result about 85% of the total wheat area follows previous rice crop (Saunders, 1991) and over 60% of the total wheat crop is cultivated at late sowing conditions (Badruddin *et al.*, 1994). Saline irrigation water is also another problem in southern part. In late planting the wheat variety should be short duration that may escape from high temperature at the grain filling stage (Phadnawis and Saini, 1992). Short duration heat shock, when maximum temperatures can exceed 35°C, wheat yield is reduced by up to 15% (Kokic *et al.*, 2005). Ansary *et al.* (1989) reported that delay sowing suppressed the yield, caused by reduction in the yield contributing traits like number of tillers, number of grains spike^{-1} and grain yield. High temperature causes pollen sterility which reduces yield.

Pollen development has been identified as the most heat-sensitive process in plant sexual reproduction, with both meiosis and gametogenesis being thermosensitive (Bokszczanin and Fragkostefanakis, 2013). Our farmers are unable to find out the heat tolerant wheat varieties for cultivation. It is important to identify the heat tolerant wheat varieties which will be easily cultivated by our farmers. And for this, the performance of wheat genotypes is observed by cultivating the varieties in two different heat conditions. After selecting wheat varieties for heat tolerance, the varieties are introduced to the farmers for increasing wheat production in Khulna region.

Considering the above circumstances this experiment was conducted with the following objectives-

- To evaluate some improved wheat genotypes exposing high temperatures during and after anthesis.
- To identify genotypes with high yield potential for cultivation in saline soil of Bangladesh.

CHAPTER II

REVIEW OF LITERATURE

Abiotic stresses are often interrelated, either individually or in combination, and they cause morphological, physiological, biochemical, and molecular changes that adversely affect plant growth and productivity, and ultimately yield. Heat, drought, cold, and salinity are the major abiotic stresses that induce severe cellular damage in plant species, including crop plants. Climatological extremes including very high temperatures are predicted to have a general negative effect on plant growth and development, leading to catastrophic loss of crop productivity. Presently, global wheat production is reduced due to climate changes which will transform these into a heat-stressed, short-season production environment. A few reports related to the present study are reviewed below-

Campbell and Read (1968) reported that Stem length and diameter were both decreased significantly ($p<0.05\%$) by increasing the moisture stress or air temperature (day, or night). Increasing day temperature from 21^0C to 27^0C or night temperature 13^0C to 21^0C did not affect tillering but the plants had shorter, silmmer culms and with smaller individual leaves, less total leaf area, less vegetative growth and less dry matter production.

Weigand and Cuellar (1981) found that significant decrease in wheat production resulted due to average temperature above 15^0C during grain filling stage.

Ahmed *et al.* (1986) reported that about 1.3% reduction in grain yield occurs for each day delay after the first day of December.

Ansary *et al.* (1989) reported that delay sowing suppressed the yield by reduction in the yield contributing traits like number of tillers, number of grains spike^{-1} and grain yield.

Wardlaw *et al.* (1989) observsd that every 1°C rise in temperature above 28°C during grain filling, results in yield reduction by 3–4 %.

Reynolds *et al.* (1994) reported that heat stress has various severe effects at different growth stages of wheat, especially at the anthesis and grain filling stages in almost all the environments.

Wardlaw and Mancur (1995) found that high temperatures can increase the grain-filling rate, but only slightly at temperatures above 20°C, which fails to compensate for the shortened duration and leads to an overall reduction in grain size.

Nicolas *et al.* (1994) have reported that losses in kernel weight (23%) of wheat occurred when the temperature was increased from 20/15ºC (day/night) to 40/15ºC on the third day after anthesis.

Stone and Nicolas (1995) reported that both long hours of exposure to moderately high temperatures (22 to 28°C) and short exposures to very high temperatures (> 30°C) affect crop development and reduce grain yield in the case of wheat.

Radmehr *et al.* (1997) reported that increasing the temperature from 21.1 to 25.9°C caused the grainfilling rate to decrease from 1.06 to 0.97 mg/grain/day, while thousand-grain weight and grain-filling period were reduced from 44.7 to 30.9 g and from 42 to 32 days, respectively.

Porter *et al.* (1998) reported that shoot growth between terminal spikelet and flowering was not modified by temperatures up to 16°C but was significantly reduced by temperatures above 19°C.

Singh and Uttam (1999) reported that each day delay in sowing from 20th November decreases grain yield 39 kg ha^{-1} per day.

Reynolds *et al.* (2001) observed that nearly 40% of total irrigated area, where wheat is grown, is severely affected by heat stress.

Mohammadi *et al.* (2001) reported that heat stress from double ridge to anthesis stages reduced grain number per unit area by 5.6% for each degree centigrade of temperature increase.

Mohammadi *et al.* (2004) observed that heat stress affects the availability and translocation of photosynthates to develop seed and starch synthesis, thus adversely affecting the grain weight and quality of wheat.

Kokic *et al.* (2005) was observed hotter and drier climate conditions anticipated in southern and western regions are predicted to reduce wheat yield by up to 15%.

Hasan and Ahmed (2005) showed that Post-anthesis heat stress in wheat induces several physiological effects which eventually result in smaller grain weight due to reduced grain filling period and starch synthesis duration or the combined effect of both.

Agar *et al*. (2006) found that high temperature stress causes a significant reduction in mean kernel number per spike and kernel weight per spike, compared with the control ($P<0.01$) and average kernel weight per spike reduced by 55% when heat stress occurred at anthesis compared with 47% at meiosis.

Tewolde (2006) and Fisher (2007) found the optimum temperature for wheat anthesis and grain filling ranges from 12 to 22°C. Exposure to temperatures above this can significantly reduce grain yield.

Rane *et al.* (2007) observed that in late sown wheat, terminal heat stress is the main cause of yield reduction which is responsible for shortening of grain growth period and improper grain filling.

Reynolds *et al.* (2007) reported that wheat-growing under hot environments show that grain number is often reduced more than might be expected from reductions in biomass, leading to relatively low harvest index under heat stress.

Hays *et al*. (2007) observed the high temperature stress during reproductive development resulting in a reduction in both individual kernel weight and kernel number.

Kosina *et al.* (2007) was reported that terminal heat stress during anthesis and grain filling period, accelerate maturity and significantly reduces grain size, and weight.

Mohammadi *et al.* (2009) has already been reported that the decline in grain yield due to heat treatment at the milky stage is due to reduced seed weight per spike. In wheat, genotypic variation with respect to translocation of assimilates from source to sink under high temperature.

Yildirim *et al.* (2009) and Dhanda and Munjal (2006) concluded from their findings that membrane thermal stability was a useful selection criterion for heat stress tolerance in wheat, reporting differences in membrane stability index among different wheat cultivars at various growth stages.

Sarker and Hakim (2011) found that wheat sown in November 22 to December 20 was significantly better compared to November 08, 15 and December 27, from the studied aspects of yield and yield components such as number of grain per spike, thousand grain yield, harvest index and straw yield.

Shefazadeh *et al.* (2012) reported that grain yield was negatively correlated with canopy temperature in both timely and late-sown wheat crops, indicating that canopy temperature always influences grain yield. However, a higher correlation coefficient under late sowing conditions showed that canopy temperature influences grain yield more strongly in the presence of heat stress. In this research, canopy temperature explained 71 and 54.2% of grain yield variation in more and less heated environments, respectively. Strong correlation was found between yield and canopy temperature under different drought levels ($P < 0.05$ and $P < 0.01$ under dryland and supplemental irrigation conditions, respectively) and heat stress ($P < 0.01$) (Mohammadi, unpublished).

Mohammad and Karimizadeh (2012) showed that in an unfavorable (late-sown) environment that was 2.1°C warmer than average during the grain-filling period decrease grain-filling duration but increase grain-filling rate. Wheat grain yield decreased by 24.1% in comparison with yield in a favorable (timely sown) environment, thousand-grain weight was reduced by 11.3% per degree centigrade of increase in mean temperature from anthesis to physiological maturity under heat stress when compared with cooler conditions.

Asseng (2011) and Lobel (2012) found that high temperatures reduced grain weight by decreasing grain growth duration, but not grain growth rate; therefore, grain weight was low due to reduced grain-filling duration.

Balla *et al.* (2012) proposed that high temperature causes grain weight reduction, early senescence, shriveled grains, reduction ofj starch accumulation, and altered starch-lipid composition in grains, lower seed germination and loss of vigour.

Zhang *et al.* (2013) showed that photosynthesis rates (Pn) decreased more rapidly under heat stress than without stress, by up to 69.9% and 59.3%, respectively, at 10 days following heat stress (10 DAS). Heat stress also caused an alteration of mesophyll cell ultrastructure, the ultrastructure of organelles such as chloroplasts, nuclei and mitochondria. Such changes in microstructure led to changes in the function of some active proteins, such as Rubisco. The observed decreases in RuBP activity inhibited photosynthetic CO2 assimilation capacity. The grain weight and grain yield also decreased under heat stress;

Khan *et al.* (2013) found that heat stress imposed at anthesis significantly increased proline concentration in leaves, the membrane stability index is decreased from 61.0 to 79.83 % under heat stress, The heat treatment significantly ($p<0.05$ %) decreased the grain yield plant-1 in all the tested wheat genotypes at anthesis growth stage.

Qayyum *et al.* (2015) was observed that total leaf protein is increased under heat stress at reproductive growth stages, total soluble proteins is increased under heat stress due to the induction of stress proteins, as such stress induced protein expression has been shown to be an important adaptive strategy of crop plants. Membrane stability index of genotypes decreased towards later developmental stages, i.e. the milky stage. Membrane instability at the milky growth stage might be associated with the beginning of senescence, the anthesis growth stage was found to be more sensitive to heat stress than seed development at the milky stage. Overall heat stress reduced yield 75% at anthesis and 40% at the milky stage.

Asseng *et al.* (2015) showed the impact of rising temperatures in their evaluation of 30 different wheat (*Triticum aestivum* L.) models to simulate wheat production. They concluded that grain production would decrease 6% per 1°C rise and become more variable in both space and time.

CHAPTER III

MATERIALS AND METHODS

This portion represents a brief description of location, crop, experimental design, treatments, cultural operations, collection of data and the method followed for physical and statistical analysis.

3.1 Experimentation

The experiments were carried out at the Dr. Purnendu Gain Field Laboratorty and Plant Breeding Laboratory of Agrotechnology Discipline, Khulna University, Khulna during the period of 04 December, 2016 to 23 March, 2017 to identify wheat genotypes for heat tolerance.

3.2 Description of the experimental site

3.2.1 Location

The growth performance of one experiment was carried out in the field condition at Dr. Purnendu Gain Field Laboratorty of Agrotechnology Discipline, Khulna University situated at Batiaghata Upazila , Khulna. The experimental site belongs to the Agro-ecological Zone of the Ganges Tidal floodplain (AEZ 13). Soil was well drained, clay-loam, electrical conductivity 6.5 dS m^{-1} (SRDI, 2017). The other experiment was carried out in the pot at Plant Breeding Laboratory of Agrotechnology Discipline, Khulna University, Khulna.

3.3 Design and layout of the experiment

Eleven genetically diverse varieties were selected and planted in Randomized Complete Block Design (RCBD) with three replication in case of field grown wheat and complete randomized design (CRD) with three replications of laboratory grown wheat. The varieties are-

T_1- BARI gom-20 (Gourab)

T_2- BARI gom-21(Shatabdi)

T_3-BARI gom-22 (Sufi)

T_4- BARI gom-23 (Bijoy)

T_5- BARI gom-24 (Prodip)

T_6- BARI gom-25

T_7- BARI gom-26

T_8- BARI gom-27

T_9- BARI gom-29

T_{10}- BARI gom-30

T_{11}- Sourov

3.4 Procedure of crop cultivation

3.4.1 Field and pot preparation

Total 136 m^2 area was prepared with the help of power tiller for field experiment. Weeds, straw and other crop residues were collected and removed from the experimental fields. The total numbers of plots were 33. The unit plot size was (1x2) m^2 and the plot to plot distance was 50 cm. For other experiment, the total numbers of pots used were 33. Each pot contains

8.00 kg of soil. Treatments were randomly distributed among the plots and pots. For both studies seeds were sown on 6 December, 2017.

3.4.2 Fertilizer application

Recommended doses of MoP, gypsum, zinc sulphate and half of TSP were applied to all experimental plots and pots during final preparation. Recommended dose of urea and rest half of TSP were applied at 25-30 days after emergence and less amount of fertilizer was given in the pots during final pots preparation. Grain samples collected from each plot and pot were weighed carefully. The yields were expressed as ton hectare^{-1} and g plant^{-1}.

3.5 Intercultural operation

3.5.1 Weeding

The experimental plots and pots were infested with some common weeds which were removed from the field by uprooting during entire period of the experiment.

3.5.2 Irrigation

Irrigation water was applied to the experimental plots and pots at fifteen days interval.

3.5.3 General observation of the experimental plots

An observation was regularly made of ten sample plants, leaves and tillers was determined in the plots and one plant in the pot.

3.6 Harvesting

Maturity of crop was determined when about 90% grains became golden yellow. The crop was harvested at full maturity at 110 days.

3.7 Sampling, threshing and processing

The harvested five crop plants of each plot and one crop plant of each pot were separately collected and properly tagged. Threshing was done carefully by hand. The grains were sun-dried to a moisture content of 14%. Straws were also sun-dried properly. Finally grain and straw yields were recorded as ton per hectare in case of plots and gram per plant in case of pots.

3.8 Data collection of growth and yield contributing parameters

3.8.1 Plant height (cm)

The plant height was measured from the ground level to the top at 10 days interval from 50 to 100 days after sowing. From each plot 10 plants were measured and averaged.

3.8.2 Number of leaves and Effective tillers plant^{-1}

The number of leaves and effective tillers per plant were counted.

3.8.3 Number of grains Spike^{-1}

Number of grains per spike was counted.

3.8.4 1000- Grains weight (g)

One thousand clean sun dried grains were counted from the grain sample obtained from the sample plants and weighed by using an electronic balance.

3.8.5 Straw yield (ton hectare^{-1}) and (g plant^{-1})

Straw samples collected from each plot were dried and weighed carefully. The yields were expressed as ton hectare^{-1}. On the otherhand straw samples collected from each pot were dried and weighed carefully. The yields were expressed as g plant^{-1}.

3.8.6 Dry matter (g plant^{-1})

Five samples plants collected from each plot were oven dried and weighed carefully. The yields were expressed as g plant^{-1}.

3.8.7 Grain yield (ton hectare^{-1}) and (g plant^{-1})

Grain samples collected from each plot and pot were dried and weighed carefully. The yields were expressed as ton hectare^{-1} and g plant^{-1} respectively.

3.9 Membrane Thermal Stability

Membrane thermal stability was determined to evaluate heat tolerant genotypes of field grown wheat. Membrane thermal stability test was done at milky stage. Fully expanded leaves were analyzed for MTS at milky stage. Eight fully expanded leaves of each genotype were collected randomly from selected plants for each replication. Each leave was divided into two parts for using as control and as heat-treatment. Halved leaves were placed into two different test tubes containing 10 ml de-ionized water and were kept for 18 hours in a refrigerator at 10^{0}C. Then the leaves were thoroughly washed with de ionized water and 15 ml deionized water was added. Then, one half each of the test tubes was kept at 25^{0}C and the other half at 45^{0}C for 1hour in water bath. Then both different heat treated samples were kept for 18 hours in a refrigerator at 10^{0}C for stabilizing the liquid compound after treatment period. Conductivity readings were taken at 25^{0}C using an electrical conductivity meter for both control (C_1) and heat treated (T_1) tubes. The samples were then boiled for 1 hour. Then both the test tubes were kept at room temperature.

A second conductivity reading of the aqueous phase (T_2 and C_2) was taken at 25^0C after the samples were cooled. Leaf membrane thermal stability was estimated using two different equations (Blum and Ebercon, 1981):

I. Membrane Thermal Stability, MTS (%) = $[1-(T_1/T_2)]$ x100

II. Relative Injury, RI (%) = $100-\{[1-(T_1/T_2)]/[1-(C_1/C_2)] \times 100\}$

Where C and T refer to electrical conductivity of control and heat treated samples, and the subscript 1 and 2 refer to electric conductivity readings before and after boiling, respectively.

For both experiments stress susceptibility index (SSI), stress tolerance index (STI), geometric mean to product (GMP), mean productivity (MP) and tolerance index (TOL) were measured by using the thermometer and calculated by following equations

$SSI= ((1-(Ys/Yp))/SI$

$STI = (Yp - Ys)/Yp$

$MP= (Yp+Ys)/2$

$TOL= Yp - Ys$

$GMP = Ys' x Yp'$

Where, Yp indicates yield of a given genotype under favorable environment (less heated environment), Ys indicates yield of a genotype in unfavorable environment (more heated environment), Yp′ indicates mean yield in favorable environment, and Ys′ indicates mean yield in unfavorable environment.

3.10 Statistical analysis

The collected data were analyzed by using Statistical Tool for Agricultural Research (STAR) following one way ANOVA based on randomized complete block design. Treatment means were separated by Duncan's New Multiple Range Test (DMRT).

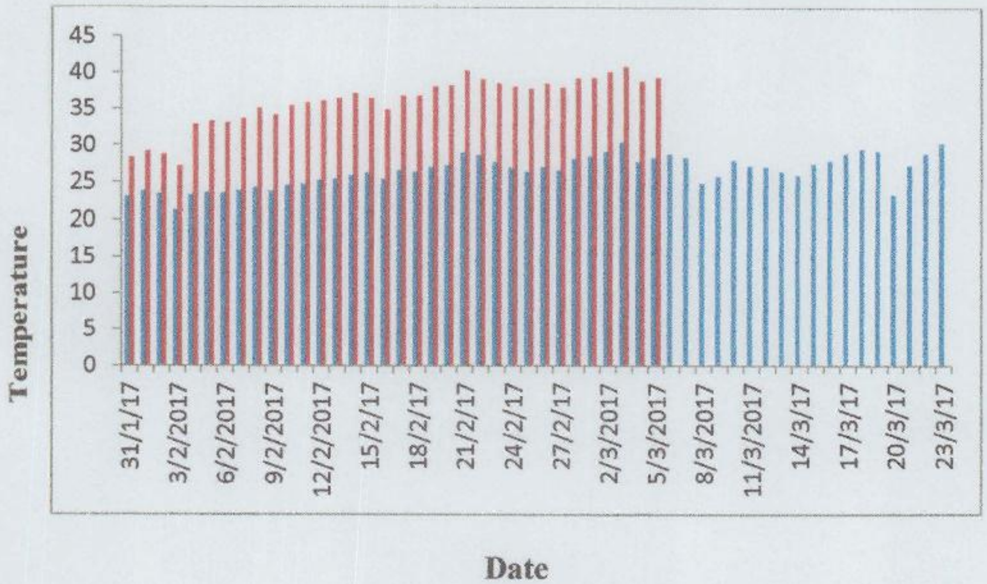
CHAPTER IV

RESULTS AND DISCUSSION

4.1Temperature record

The average temperature was recorded for laboratory and field experiment. Temperature was recorded at four times in a day for both the experiments. The laboratory temperature was higher than field temperature. The red color indicates laboratory temperature and blue color indicates field temperature (Figure 1). The minimum field temperature was 21.3^{0}C and the maximum field temperature was 30.4^{0}C. In case of laboratory the minimum temperature was 27.1^{0}C and the maximum temperature was 40.3^{0}C (Figure 1). Here blue color indicates field temperature and red color indicates laboratory temperature.

Figure1: The average temperature recorded in both the experiments



4.2 Plant height (cm)

Plant height is very essential production component as result of photosynthetic activity. The average plant heights of wheat crops at different days are shown in Table 1. There was significant difference in plant height among the plots and pots (Table 2 and Table 3). The highest (92.63 cm) plant height was found in BARI gom-24 (prodip) and the lowest (79.57 cm) in BARI gom-30 under less heated field condition. On the other hand the plant height is the highest (47.33 cm) in BARI gom-26 and the lowest (34.93 cm) in BARI gom-30 under more heated laboratory condition. The average plant height was high in less heated condition than the more heated condition. Austin and Jones (1975) reported that most of the variations in the plant height variations are attributable to differences in internode length rather than internode number. Hossain *et al.* (2012) supported the result that all wheat varieties, when sown late, faced severe temperature stress that significantly affected phenology, growth and finally yield.

4.3 Leaf number plant^{-1}

There was a significant difference in leaves number among the genotypes (Table 2 and Table 3). Maximum number of leaf (25) was found in BARI gom-21 (Shatabdi) and minimum number of leaf (15) was found in BARI gom-30 under less heated field condition. On the other hand maximum number of leaf (13) was found in BARI gom-21(shatabdi) and minimum number of leaf (5.00) was found BARI gom-25 under more heated laboratory condition. The number of leaf is decreased with the increase of temperature. Reduction in total number of leaves and spike bearing tillers is also an effect of high temperature during this phase (Midmore *et al.*, 1984). The sensitivity to high temperature during this phase is expressed as decreased duration of global stability index of leaf (Shpiler and Blum, 1986) and reduced leaf area and growth.

4.4 Number of tillers plant^{-1}

There was a significant difference in tiller number per plant among the genotypes (Table 2). Maximum number of tiller per plant (4.33) was found in BARI gom-24 (prodip) and BARI gom-21 (shatabdi) and minimum number of tiller per plant (3.00) was found in most of the genotypes under less heated condition. In case of more heated condition, there was no tiller in the plant. O'Toole and Stockle (1991) reported that the sensitivity to high temperature increases at vegetative growth stage and tillering proceeds towards the end of GSI (emergence of ridge stage).

Table1: Effect of varieties on plant height at different days under relatively less heated condition (20-30 °C) of field grown wheat

Variety	Plant height at 50 days (cm)	Plant height at 60 days (cm)	Plant height at 70 days (cm)	Plant height at 80 days (cm)	Plant height at 90 days (cm)	Plant height at 100 days (cm)
BARI gom-20 (Gourab)	29.23 abc	44.97 abc	55.57 bcd	66.97c	80.93a	87.93 ab
BARI gom-21(Shatabdi)	32.23 a	48.73 a	60.97 a	72.53 a	81.37 ab	92.20 a
BARI gom-22 (Sufi)	27.23 abc	41.77 bcd	56.80 b	69.73 abc	76.87 cdef	85.13 bc
BARI gom-23 (Bijoy)	27.20 abc	42.37 bcd	55.70 bcd	67.07 bc	76.13 def	86.30 bc
BARI gom-24 (Prodip)	30.40 ab	48.13 a	59.13 ab	72.37 a	81.00 abc	92.63 a
BARI gom-25	30.10 ab	45.53 ab	57.17 b	71.03 ab	77.50 bcde	83.90 bcd
BARI gom-26	28.77 abc	44.07 abc	55.87 bcd	70.43 abc	79.37 abcd	88.10 ab
BARI gom-27	28.67 abc	42.10 bcd	55.77 bcd	66.60 c	75.80 def	82.90 cd
BARI gom-29	26.57 bc	40.40 cd	53.07 cd	68.03 bc	73.67 ef	80.03 d
BARI gom-30	24.47 c	38.83 d	52.37 d	65.60 abc	72.57 f	79.57 d
Sourov	27.13 abc	41.73 bcd	56.57 bc	69.37 abc	76.90 cde	83.57 bcd
CV (%)	6.16	3.98	2.22	1.97	1.89	1.95
LS	**	**	**	**	**	**

Here,

LS = Level of significance

** = Significant at 1% level of probability

Table 2: Effect of varieties on plant height (cm) , number of leaves plant^{-1} , effective tillers number plant^{-1} , number of grain spike^{-1}, grain yield (ton ha^{-1}), 1000 grain weight (g), straw yield and harvest index (%) under relatively less heated condition (20-30 °C) of field grown wheat.

Treatment	Plant Height (cm)	Number of leaves plant^{-1}	Effective tillers number plant^{-1}	Number of grain Spike^{-1}	1000 grain weight (g)	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})	Hervest Index (%)
BARI gom-20 (gourab)	87.93 ab	20.00 ab	3.33 ab	45.00 cde	42.00 bcd	2.39 bc	3.34 b	41.71 a
BARI gom-21(shatabdi)	92.20 a	25.00 a	4.33 a	46.67 bcd	45.33 abc	2.81 ab	5.14 a	35.33 cd
BARI gom-22 (sufi)	85.13 bc	20.67ab	3.33 ab	51.67 abc	39.33 cd	2.00 cdef	3.82 b	34.37 de
BARI gom-23 (bijoy)	86.30 bc	20.67 ab	3.00 b	39.00 ef	46.00 abc	2.04 cde	3.67 b	35.70 cd
BARI gom-24 (prodip)	92.63 a	22.67 a	4.33 a	54.67 a	54.00 a	3.01 a	4.15 a	42.03 a
BARI gom-25	83.90 bcd	18.67 ab	3.00 b	40.67 def	48.67 ab	1.90 defg	3.48 b	35.17 cd
BARI gom-26	88.10 ab	19.33 ab	3.00 b	46.67 bcd	45.00 bcd	2.38 bcd	3.52 b	40.30 ab
BARI gom-27	82.90 cd	18.67 ab	3.00 b	39.33 def	41.67 bcd	1.83 efg	3.50 b	34.27 def
BARI gom-29	80.03 d	18.33 ab	3.00 b	36.00 f	37.67 cd	1.55 fg	3.42 b	31.27 ef
BARI gom-30	79.57 d	15.00 b	3.00 b	35.67f	36.33 d	1.44 g	3.21 b	30.97 f
Sourov	83.57 bcd	20.00 ab	3.00 b	53.33 ab	42.00 bcd	2.22 cde	3.14 b	41.40 ab
CV (%)	1.95	10.88	10.93	5.75	6.86	7.64	7.64	3.14
LS	**	**	**	**	**	**	**	**

Here,

LS = Level of significance

** = Significant at 1% level of probability

4.5 Number of grain spike^{-1}

Number of grains spike^{-1} is very important component contributing toward grain yield. The number of grains per spike resulting the number of spikelets formed and the number of fertilized flowers, the latter being defined between meiosis and anthesis. There was significant difference in number of grain per spike among genotypes under less heated condition (Table 2). It was observed that the highest number of grains spike^{-1} (54.67) was highest in BARI gom-24 (prodip) and the lowest number of grains spike^{-1} (35.67) in BARI gom-30 under less heated condition. However, the number of grains per spike among the genotypes was observed non-significant under more heated condition (Table 3). However the highest number of grains spike^{-1} (9.00) wass high in BARI gom-26 and the lowest number of grains spike^{-1} (2.67) in BARI gom29 under more heated condition. The average grain production is high under less heated condition than more heated condition. Farooq *et al.* (2011) reported that the reduction in the number of grains per spike can be attributed to the heat effect on the differentiation of floral organs, male and female sprogensis, pollination and fertilization. Rahman *et al.* (2009) found that high temperatures affect pollen viability, reducing the number of fertilized flowers. Owen (1971) and Saini and Aspinal (1982) reported that temperatures above 30°C during floret formation cause complete sterility, ultimately reduced grains spike^{-1}.

4.6 1000 grain weight (g)

There was significant difference in 1000-grain weight among the genotypes (Table 2). The highest 1000- grain weight (54.00 g) was found in BARI gom-24 (prodip) and the lowest 1000-grain weight (36.33 g) was found in BARI gom-30 under less heated condition. On the other hand the 1000-grain weights among genotypes are non-significant under more heated condition (Table 3). The highest 1000- grain weight (22.19 g) is found in BARI gom-20 (gourab) and lowest 1000-grain weight (12.5 g) is found in BARI gom-30 under more heated condition. A subsequent decrease in 1000 grain weight in wheat with delayed sowing was reported by Joarder *et al.* (1981). Similar result was also found by Sofied *et al.* (1977), they reported that higher grain weight was observed due to favourable temperature associated with longer grain filling period. These findings are strongly supported by those of Spink *et al.* (2000) and Shahzad *et al.* (2002) who had also reported decreased 1000-grain weight with delay in sowing. Similar results have been reported in the past (Qamar *et al.*, 2004; Subhan *et al.*, 2004).

4.7 Grain weight (ton ha^{-1})

There was significant difference in grain yield among the different genotypes (Table 2). The highest grain weight (3.01 t/ha) was found in BARI gom-24 (prodip) and the lowest grain weight (1.44 t/ha) was found in BARI gom-30 under less heated condition. Under more heated condition the grain yield among the genotypes were non-significant (Table 3). Numerically the highest grain weight (0.14 g/plant) is found in BARI go-m26 and BARI gom-27 and the lowest grain weight (0.05 g/plant) was found in BARI gom-30 under more heated condition. The grain yield is decreased with the increase of temperature. Wahid *et al.* (2007) found that excess radiation and high temperatures are the most limiting factors affecting plant growth and finally crop yield in tropical environment. Sing *et al.* (1986) found that grain yield of barley decreased at delayed sowing from 10-25 December and 10 January. Hasan *et al.* (2002) stated that grain yield reduction was 2.6 to 5.8% in heat tolerant and 7.2% in heat sensitive genotypes for each 1°C rise in average mean air temperature from optimum condition during anthesis to maturity.

4.8 Harvest index (%)

Harvest index is the important components for selecting high yielding genotypes under normal and more heated condition. There was significant difference in harvest index among the genotypes (Table 2). The highest harvest index (42.03%) is found in BARI gom-24 (prodip) and the lowest harvest index (30.97%) was found in BARI gom-30 under less heated condition. On the other hand the harvest index among genotypes was non-significant under more heated condition (Table 3). The highest harvest index (33.33%) is found in BARI gom-26 and the lowest harvest index (14.33%) was found in BARI gom-29 under more heated condition. High harvest index, which is indicative of efficient utilization of photosynthates, was also associated with high yields under the stress condition (Gifford *et al.*, 1984; Blum *et al.*, 1994). A simple linear regression using harvest index as independent variable and yield as dependent variable showed positive relationship of both field and laboratory grown wheat (Figure 2 and Figure 3). The value of R^2 (0.56) indicates that about 56% variation in yield could by the variation in harvest index of field grown wheat. But for laboratory grown wheat, about 72% variation in yield could by the variation in harvest index (R^2 =0.72).

Table 3: Effect of varieties on plant height (cm), number of leaves plant^{-1}, tiller number plant^{-1}, number of grain/spike, grain yield (g plant^{-1}), 1000 grain weight (g), straw yield (g plant^{-1}) and harvest index (%)under relatively more heated condition (25-40^{o}C) of laboratory grown wheat.

Variety	Plant Height (cm)	Number of leaves plant^{-1}	Number of grain Spike^{-1}	1000 grain weight (g)	Grain yield (g plant^{-1})	Straw yield (g plant^{-1})	Hervest Index (%)
BARI gom-20 (Gourab)	39.57 de	8.33bcde	5.67	22.19	0.12	0.31 ab	32.39
BARI gom-21(Shatabdi)	37.50 def	13.00 a	5.00	21.11	0.10	0.30 ab	25.65
BARI gom-22 (Sufi)	45.40 ab	8.67 bcd	5.00	18.00	0.09	0.34 a	19.55
BARI gom-23 (Bijoy)	42.73 bc	6.00 ef	5.00	13.85	0.1	0.31 ab	22.21
BARI gom-24 (Prodip)	42.73 bc	6.67 def	7.33	17.80	0.13	0.33 ab	28.44
BARI gom-25	36.60 ef	5.00 f	8.67	14.99	o.13	0.26 b	29.25
BARI gom-26	47.33 a	9.33 bc	9.00	15.55	0.14	0.28 ab	33.33
BARI gom-27	40.50 cd	7.00 cdef	7.33	19.62	0.14	0.33 a	29.57
BARI gom-29	37.63 def	5.67 f	2.67	14.13	0.06	0.31 ab	14.33
BARI gom-30	34.93 f	10.00 b	4.00	12.5	0.05	0.19 c	21.56
Sourov	38.97 de	6.33 def	6.67	16.49	0.11	0.28 ab	25.09
CV (%)	2.58	10.47	74.27	55.79	67.72	7.81	62.81
LS	**	**	NS	NS	NS	**	NS

Here,

LS = Level of significance

** = Significant at 1% level of probability

NS = Non-significant

4.9 Straw yield

There was significant difference in straw yield among the genotypes under less and more heated condition (Table 2 and Table 3). The highest straw yield is found in BARI gom-21 (shatabdi) and lowest straw yield is found in Sourov under less heated condition. Therefore the highest straw yield is found in BARI gom-22 (sufi) and lowest straw yield is found in BARI gom-30 under more heated condition. The average straw yield is high in less heated condition than more heated condition. Kumer *et al.* (1994) reported that the straw yield decreased probably due to the fact that plant got unfavorable environment (high temperature) at vegetative stage, as a result crop became thinned and produced less tillers which in turn decreased the straw yield. A simple linear regression using straw yield as independent variable and yield as dependent variable showed positive relationship of both field and laboratory grown wheat (Figure 4 and Figure 5). The value of R^2 (0.42) indicates that about 42% variation in yield could by the variation in straw yield of field grown wheat. However about 33% variation in yield could by the variation in straw yield (R^2 =0.33) of laboratory grown wheat.

4.10 Dry matter

Results of the experiment indicated that total dry matter production was increased with the increase of growth stage. There was a significant difference in dry matter accumulation of plant at different days (Table 4). The result revealed that the increasing rate of dry matter accumulation of plant is high in BARI gom-21 (shatabdi) and in BARI gom30 under less heated condition.

Table 4: Effect of varieties on dry matter of plant at different days under relatively less heated condition (20-30 °C) of field grown wheat.

Variety	Dry weight (g $plant^{-1}$) at 60 days	Dry weight (g $plant^{-1}$) at 70 days	Dry weight (g $plant^{-1}$) at 80 days	Dry weight (g $plant^{-1}$) at 90 days	Dry weight (g $plant^{-1}$) at 100 days	Dry eight (g $plant^{-1}$) at 110 days
BARI gom-20 (Gourab)	7.55 bcd	10.94 b	13.77 b	17.57 b	20.14 bcd	24.22 sabc
BARI gom-21(Shatabdi)	9.06 ab	13.78 a	16.86 a	19.93 a	23.00 ab	26.41 a
BARI gom-22 (Sufi)	6.52 cdef	10.25 bc	13.11 bc	16.47 bc	20.47 bc	24.13 abcd
BARI gom-23 (Bijoy)	7.21 bcde	10.76 bc	13.37 b	16.23 bc	19.53 cde	23.40 bcd
BARI gom-24 (Prodip)	10.55 a	14.01 a	17.28 a	21.32 a	23.54 a	26.28 a
BARI gom-25	4.84 ef	8.24 cd	11.64 bcd	15.38 cd	17.40 def	22.13 cd
BARI gom-26	8.47 abc	10.42 bc	13.65 b	16.77 bc	21.33 abc	25.05 ab
BARI gom-27	5.36 def	8.46 bcd	11.65 bcd	14.92 cd	16.71 ef	22.79 bcd
BARI gom-29	4.52 f	7.63 d	10.89 cd	13.35 de	15.58 f	21.79 cd
BARI gom-30	4.29 f	6.45 d	9.73 d	12.60 e	15.51f	21.40 d
Sourov	5.49 def	8.92 bcd	13.02 bc	16.14 bc	18.90 cde	23.35 bcd
CV (%)	12.34	8.77	6.36	4.51	5.20	4.02
LS	**	**	**	**	**	**

Here,

LS = Level of significance, ** = Significant at 1% level of probability

4.11 Membrane Thermal Stability (MTS)

Membrane thermal stability of leaf was measured for high heat tolerance through MTS test in wheat genotypes is shown in Table 5. There was a significant difference in membrane thermal stability of leaf among the genotypes (Table 5). Results showed that the highest membrane thermo-stability (84.64%) was found in BARI gom-24 (Prodip) which was closely followed by BARI gom-21 (Shatabdi) (77.66%), BARI gom-20 (Gourab) (65.27%) and BARI gom-26 (56.12%). But the lowest membrane thermostability is found in BARI gom-30 (16.02%). In this study, the membrane thermostability, wheat genotypes BARI gom-21 (Shatabdi), BARI gom-20 (Gourab) and BARI gom-26 were considered as heat tolerant (HT) due to their higher (>55%) membrane thermal stability value.

High temperatures at seedling growth stage decreased MTS in wheat (Efeoglu and Terzioglu, 2007). The MTS assay is also associated with genetic variability under drought while physiological traits such as photosynthesis, stomatal conductance and canopy temperature depression are related mainly with heat tolerance (Blum, 1988). It was reported differences for membrane permeability within bread and durum wheat species concerning the capability to cope with high temperatures at the stage of grain filling (Dias *et al.*, 2009). A simple linear regression using membrane thermal stability as independent variable and yield as dependent variable showed positive relationship of field grown wheat (Figure 6). The value of R^2 (0.35) indicates that about 35% variation in yield could be due to the variation in membrane thermal stability of field grown wheat.

4.12 Relative injury

The heat tolerant genotypes had less membrane injury compared to susceptible ones. There was a significant difference in membrane injury of leaf among the genotypes (Table 5). Results showed that the highest membrane injury (81.74%) was found in BARI gom-30 which was closely followed by BARI gom-29 and BARI gom-27. The lowest membrane injury (2.73%) was found in BARI gom-21 (Shatabdi) which was closely followed by BARI gom-20 (Gourab) and BARI gom-26. Heat injury to the plasmalemma may be measured by ion leakage (Chaisompongpan *et al.,* 1990; Hall, 1993). Injury to membranes from a sudden heat stress event may result from either denaturation of the membrane proteins or from melting of membrane lipids which leads to membrane rupture and loss of cellular contents (Ahrens and Ingram, 1988). A simple linear regression using relative injury as independent variable and yield as dependent variable showed negative relationship of field grown wheat (Figure 7), and about 36% variation in yield could by the variation in relative injury of field grown wheat (R^2 =0.36).

Table 5: Effect of varieties on membrane thermal stability and relative injury of field grown wheat.

Variety	Membrane thermal stability (%)	Relative injury (%)
BARI gom-20 (Gourab)	65.72 c	17.03 g
BARI gom-21(Shatabdi)	77.66 b	7.20 h
BARI gom-22 (Sufi)	38.00 f	58.92 c
BARI gom-23 (Bijoy)	46.51 e	44.59 d
BARI gom-24 (Prodip)	84.64 a	2.73 h
BARI gom-25	32.38 g	63.54 c
BARI gom-26	56.12 d	32.67 f
BARI gom-27	25.98 h	69.23 b
BARI gom-29	19.22 i	77.96 a
BARI gom-30	16.02 i	81.74 a
Sourov	49.26 e	40.03 e
CV (%)	2.94	4.09
LS	**	**

Here,

LS = Level of significance

** = Significant at 1% level of probability

4.13 Different stress indices

In our study, all the stress indices among genotypes were non-significant (Table 6). Estimation of SSI indices revealed that, the genotypes BARI gom-24 (prodip), BARI gom-23 (bijoy), BARI gom-22 (sufi), BARI gom-21(shatabdi), BARI gom-26, Sourov and BARI gom-20 (gourab) had the lowest SSI (0.9%) value and therefore these genotypes had lowest heat susceptibility and high yield stability.

Hence, low stress susceptibility indices (SSI<1) is synonymous with high stress tolerance (Fisher and Maurer, 1978). On the other hand BARI gom-25, BARI gom30, BARI gom-29 and BARI gom-27 had higher SSI value and therefore these genotypes had high heat susceptibility and low yield stability.

This result supports the findings of several authors (Bruckner and Frohberg, 1987; Ehdaie *et al.*, 1988; Bansal and Sinha, 1991; Khanna-Chopra and Viswanathan, 1999) all of whom confirmed that high stability in grain yield under stress was associated with poor or moderate grain yield potential.

It has been evident in literature that SSI could be a more useful index in discriminating better genotypes under drought stress condition (Golabadi *et al.*, 2006; Talebi *et al.*, 2009; Nouri *et al.*, 2011). In our experiment, the stress tolerance index (0.04%) is highest in BARI gom-26 and tolerance index (5.44%) and geometric mean to product (0.74%) is high in BARI gom-24 (prodip). Lowest tolerance index (2.33%) and geometric mean to product (0.34%) is found in BARI gom-30.

The response of wheat to both chronic heat stress (Tashiro and Wardlaw 1990; Wardlaw *et al.*, 1989; Yang *et al.* 2002a, b, c) and short term heat shock (Hays *et al.*, 2007; Plaut *et al.*, 2004; Tashiro and Wardlaw 1990) is well documented and many of the current wheat grown in the Southern Great Plains region have shown susceptibility in terms of their inability to maintain yield and quality under high temperature (Hays et al., 2007 and Yang et al., 2002b).

Table 6: Mean grain yield in less and more heated conditions, different stress indices for wheat genotypes

Variety	(y_p) Grain yield of favorable condition (g plant^{-1})	(y_s) Grain yield of unfavorable condition (g plant^{-1})	Stress susceptibility index (SSI) %	Stress tolerance index (STI) %	Tolerance index (TOL) %	Geometric mean to product (GMP) %
BARI gom-20 (gourab)	4.43 b	0.12	0.99	0.03	4.51	0.74
BARI gom-21(shatabdi)	4.63 bc	0.10	.99	0.03	4.74	0.70
BARI gom-22 (sufi)	3.72 ef	0.09	0.99	0.02	3.63	0.58
BARI gom-23 (bijoy)	3.90d ef	0.08	0.98	0.02	3.82	0.56
BARI gom-24 (prodip)	5.54 a	0.1	0.99	0.03	5.44	0.74
BARI gom-25	3.56 f	0.13	1.00	0.03	3.42	0.49
BARI gom-26	4.84d	0.14	0.99	0.04	4.30	0.75
BARI gom-27	3.48 fg	0.09	1.00	0.02	3.39	0.56
BARI gom-29	2.91 gh	0.06	1.01	0.02	2.85	0.42
BARI gom-30	2.38 h	0.05	1.01	0.02	2.33	0.34
Sourov	4.21 cde	0.11	0.99	0.02	4.1	0.68
CV (%)	4.94	79.56	2.12	81.72	61.69	67.29
LS	**	NS	NS	NS	NS	NS

Here, LS = Level of significance, ** = Significant at 1% level of probability, NS= Non-significant

Relation between the yield parameters of field grown and laboratory grown wheat

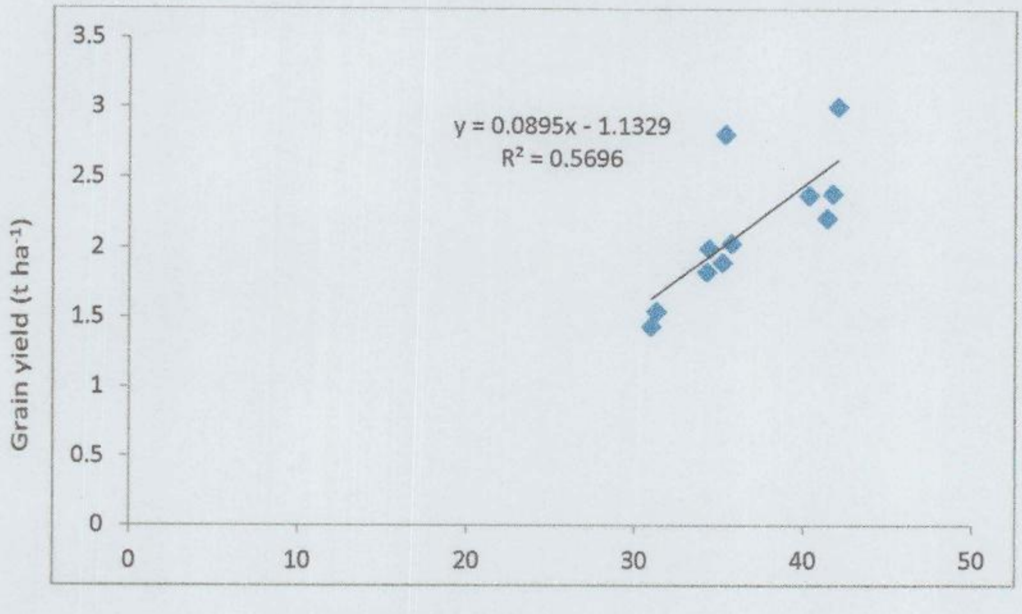


Figure 2: Functional relationship between grain yield (t ha^{-1}) and harvest index (%) of field grown wheat

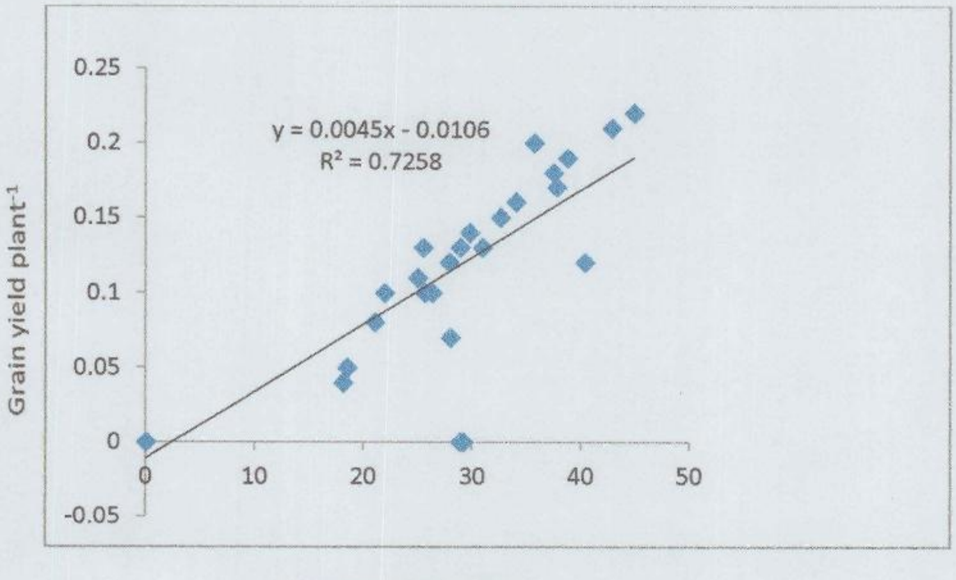
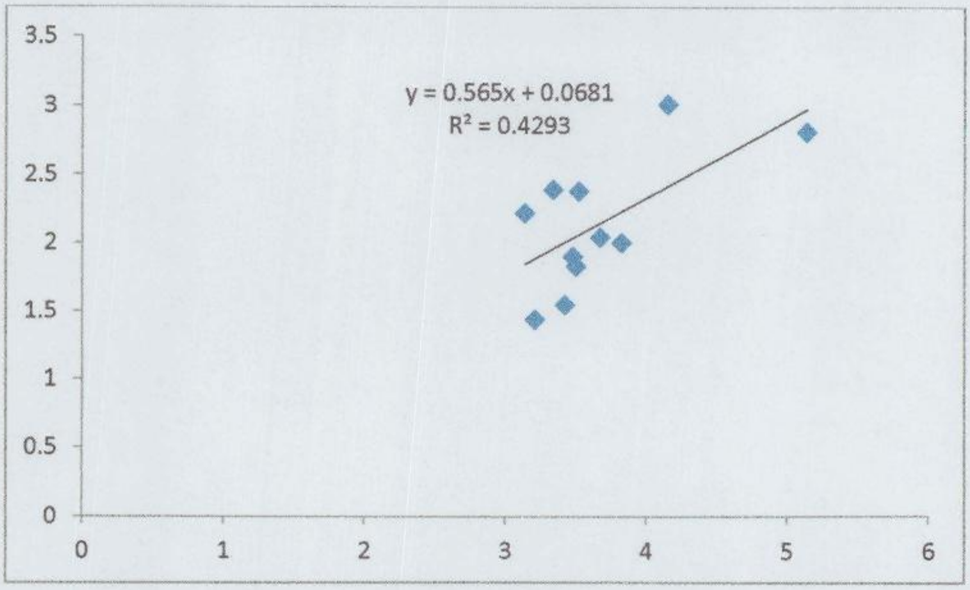


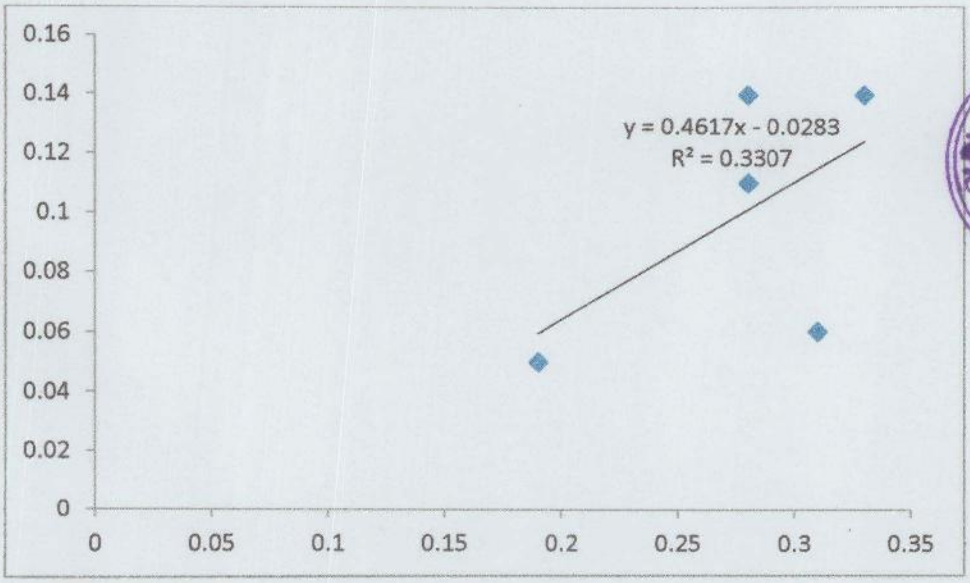
Figure 3: Functional relationship between grain yield (g $plant^{-1}$) and harvest index (%) of laboratory grown wheat

Relation between grain yield (t/ha) and and straw yield



Straw yield (t ha^{-1})

Figure 4: Functional relationship between grain yield (t ha^{-1}) and Straw yield (t ha^{-1}) of field grown wheat



Straw yield (g $plant^{-1}$)

Figure 5: Functional relationship between grain yield (g $plant^{-1}$) and Weight of straw (g $plant^{-1}$) of laboratory grown wheat

Relation between grain yield (t/ha) and membrane thermal stability (%)

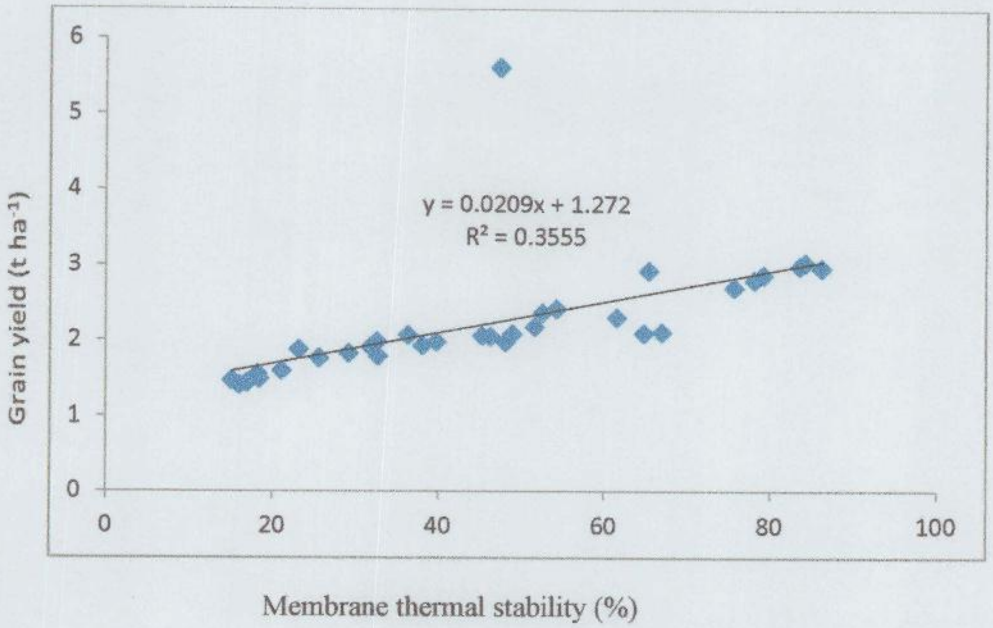


Figure 6: Functional relationship between grain yield (t ha^{-1}) and membrane thermal stability (%) of field grown wheat

Relation between grain yield (t/ha) and relative injury (%)

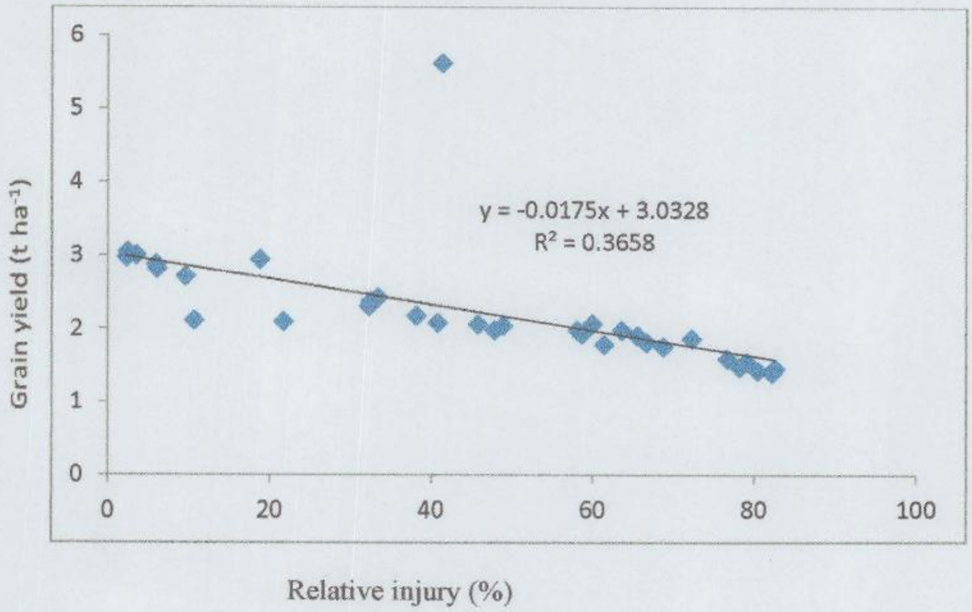


Figure 7: Functional relationship between grain yield (t ha^{-1}) and relative injury (%) of field grown wheat

CHAPTER V

SUMMARY AND CONCLUSION

Two experiments were conducted at the Dr. Purnendu Gain Field Laboratorty and green house of Agrotechnology Discipline, Khulna University, Khulna during the period of 04 December, 2016 to 23 March, 2017 to identify wheat genotypes for heat tolerance under different heat condition.

The experiments were laid out in randomized complete block design (RCBD) and complete randomized design (CRD) with three replications. Eleven wheat genotypes viz., BARI gom-20 (Gourab), BARI gom-21(Shatabdi), BARI gom-22 (Sufi), BARI gom-23 (Bijoy), BARI gom-24 (Prodip) BARI gom-25, BARI gom-26, BARI gom-27, BARI gom-29, BARI gom-30 and Sourov were used as study material.

The estimation of different stress indices, yield components and membrane thermostability test are important technique to identify genetic variability in high temperature tolerance in wheat genotypes within a short time period and suitable for screening genotypes and needs further confirmation at molecular levels. Plant height, number of leaves/plant, tillers number/plant, number of grains/spike, total grain weight, 1000-grain weight, straw weight and harvest index were recorded. Data were statistically analysed by ANOVA.

It was also found that the highest membrane thermal stability, tolerance index, geometric mean to product and stress tolerance index with lowest membrane injury and stress susceptible index are found in BARI gom-24 (prodip) which was closely followed by BARI gom-21 (shatabdi), BARI gom-20 (gourab) and BARI gom-26.

We found that the highest yield components are found in BARI gom-24 (prodip) which was closely followed by BARI gom-21 (shatabdi), BARI gom-20 (gourab) and BARI gom-26 and lowest in BARI gom-30 under less heated condition. On the other hand the highest yield components are found in BARI gom-26 and BARI gom-27 which was closely followed by

BARI gom-24 (prodip), BARI gom-25, BARI gom-20 (gourab) and Sourov and lowest in BARI gom-30 under more heated condition.

Overall results indicate that BARI gom-24 (prodip), BARI gom-21(shatabdi), BARI gom-20 (gourab) and BARI gom-26 are heat tolerant and BARI gom-30 is the most heat susceptible genotypes.

CHAPTER VI

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